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Experiments of the Charging Mechanism of Ice Particles by the Ion–Capture Process

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Abstract

In order to clarify "the inverse relation" and "the mirror image relation" between the atmospheric electric field strength and the electric charges on precipitation particles, experiments of the charging mechanism of precipitation particles by "the ion-capture process" were carried out using metallic models and natural precipitation particles. As a result, although dendrites and snowflakes have a number of small openings, their final charges obtained by the ion-capture depended on their external shapes and diameters. Therefore, it was regarded as appropriate to approximate dendrites to conducting disks and snowflakes to spherical conductors. It was expected that the high porosity of snow crystals leads to the increase the collection efficiency of ions. As a result, snow crystals require a shorter time to reach the final charges than rain drops with no porous surface.

1. Introduction

It is well known that there is an inverse relation between the atmospheric electric field strength (potential gradient) and the electric charges on precipitation particles observed on the ground surface. This relation is called "the mirror image relation" (Chalmers, 1976; Magono, 1980) when the time variation of both elements are symmetrical in positive and negative signs inserting the horizontal axis of time, for instance, positive electric field to negative electric charge and vice versa. Moreover, recently, a report is available in which the definition of this relation differs between the types of precipitation particles (Kikuchi et al., 1979). For instance, the mirror image relation in the cases of falling snowflakes is clearer than that of falling rain drops. On the other hand, as compared with the charges on precipitation particles of the same mass, it is reported that the charge on snowflakes is greater than that on rain drops (Tsuboya and Kikuchi, 1983). We are of the opinion that one of reasons of this is caused by the Wilson's ion-capture

process (Wilson, 1929). That is to say, the precipitation particles capture the ions produced by point discharge on the ground during their falling. Whipple and Chalmers (1944) calculated the time variation rate of charges on water drops by Wilson's ion-capture process in detail. According to their calculation, the final charge of drops (sphere) Q for negative ions only is as follows; $Q=-3Ea^2$ (esu), where E is the electric field strength and a is a radius of the drop. Further, an experiment to simulate the capture of ions was conducted with water drops and ice spheres with their smooth and irregular surfaces by Abbas and Latham (1967). Recently attention on snow crystals was focused on the experiments by Richard et al. (1981). They made accurate metallic models for each shape of snow crystals and measured the final charge per unit cross-sectional area of those models. Twenty years ago, on the other hand, McDonald (1963) suggested that the capacitance of the snow crystal did not depend on the microstructure of the crystals. In this paper, we have attempted to determine whether we could simply describe the final charges on snowflakes. Hence, we made experiments with metallic models and natural ice particles.

2. Experimental apparatus

Fig. 1 shows the experimental apparatus of the final charges on the metallic model spheres and natural ice particles. A wooden box shielded externally ($35\ cm^W \times 60\ cm^D \times 35\ cm^H$) was used as the experimental chamber. To produce the electric field, two aluminum disks 25 cm in diameter were used as high voltage electrodes. They were separated from each other by 10 cm in parallel, and were supported by insulators. One of these was grounded,

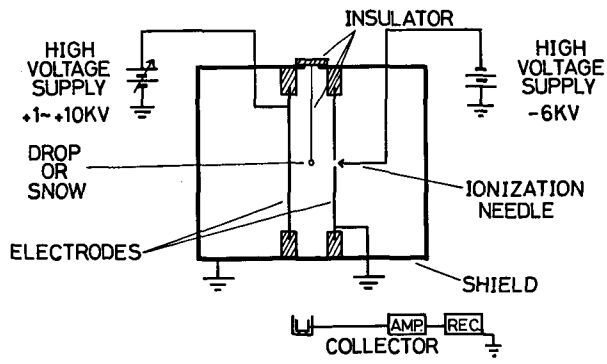

Fig. 1 Experimental apparatus.

the other connected to a positive high voltage supply (1~10KV). As the grounded electrode had small holes, through the holes, negative ions generated between the grounded electrode and the ionization needle connected to a negative high voltage supply (-6KV) were supplied between the electrodes. Metallic model spheres and artificial or natural ice particles were suspended among the electrodes by an insulated thread in order to expose them for a sufficient time to capture the ions.

The experimental procedure is as follows; First a metallic model sphere and an artificial or natural ice particle was grounded before the operation. Next the electric field was supplied between electrodes and ionization was carried out. After the artificial spheres and particles captured enough ions, the ionization was discontinued. The charges on the particles were measured with a Faraday cage type electrometer.

3. Experimental results

3.1 Results of water drops

First, an electrification experiment on water drops was carried out in the same way as in Abbas and Latham's experiment (1967). The electric field supplied between electrodes was varied from 10 to 100KV·m^{-1}. The experimental results are shown in Fig. 2. In the figure, the vertical and horizontal axes show the electric charge and the square of radius of water drops, respectively. In general, water drops are electrically regarded as conductive spheres. Therefore, straight lines in the figure show theoretical final charges on them. Although measured values were found scattered around the theoretical lines under all electric fields supplied, they agreed with those of the Abbas and Latham's results (1967).

3.2 Results of metallic models of ice particles

Second, the final charges of metallic models for ice particles were examined. A lead disk 0.25 mm in thickness regarded as plane snow crystals such as "dendrite" and "stellar" was hung oriented perpendicular to the electric field. And the final charges on the lead disk by an ion-capture process were measured. Fig. 3 shows the results between the final charge and the square of radius when the electric field supplied were 10KV·m^{-1} and 20KV·m^{-1}, respectively. The final charges are proportional to the square of radius and to the electric field supplied. The experimental formula is

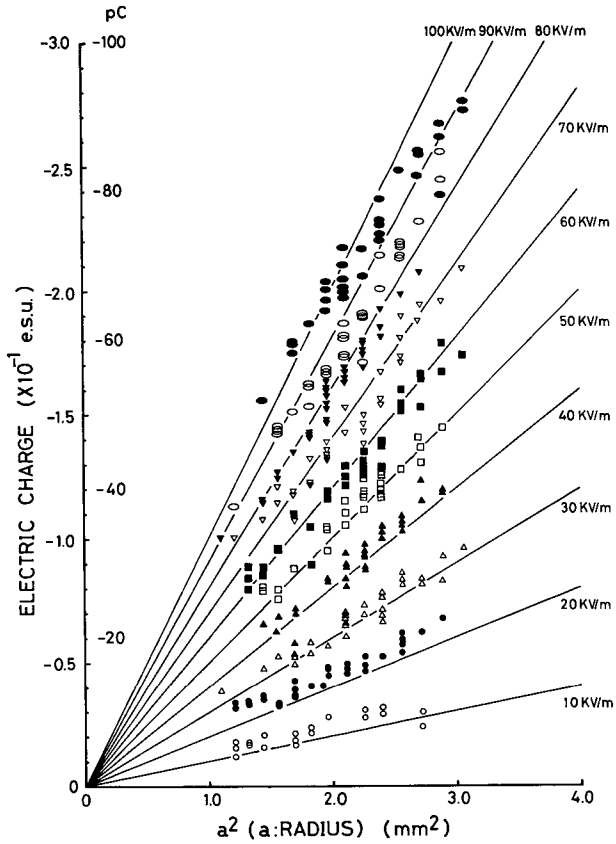

Fig. 2 Relation between electric charge and square of radius of water drops under various electric fields.

$$Q = -0.844Ea^2 \qquad \text{(esu)}\,.$$

The final charges of this metallic model are about 0.35 times of that of electric conductive spheres.

To simulate natural snow crystals of "dendrite" or "stellar" types, pin holes were opened in a similar lead disk (7 mm in diameter, 0.25 mm in thickness). The results are shown in Fig. 4. Two types of perforated disks were examined. In one case, (A) on the left side of Fig. 4, the area of the lead disk was decreased by many small holes (the diameter of each hole is 1 mm) simulating dendritic crystals. In the lower part of the left figure, the number of perforations and the percentage of the area are shown. In another case, (B) on the

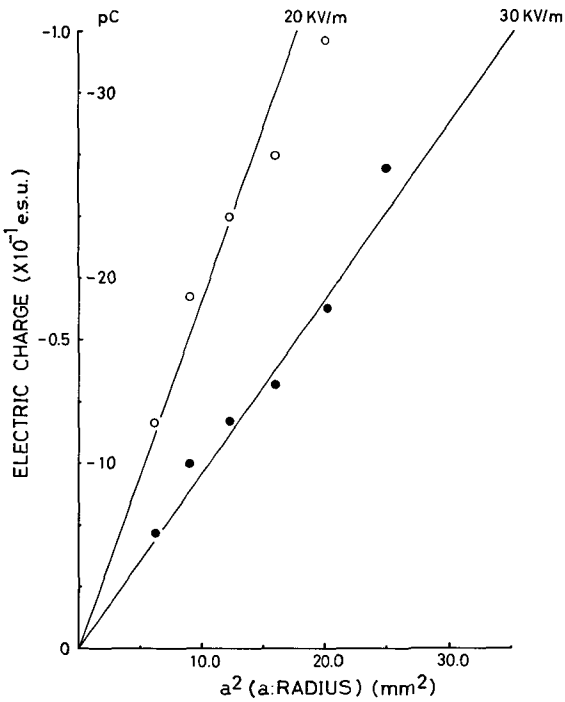

Fig. 3 Relation between electric charge and square of radius of metallic models for ice particles under electric fields of 10 and 20KV·m^{-1}.

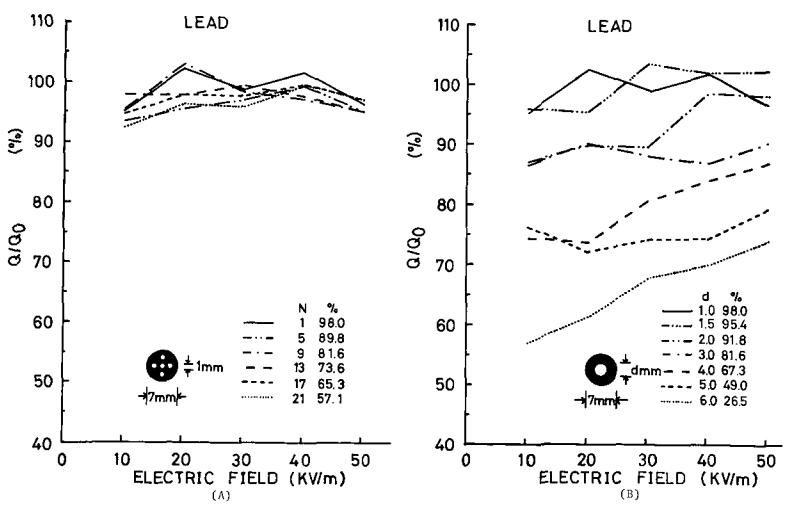

Fig. 4 Relation between the ratio of final charges of perforated disk (Q) to non-perforated disk (Q_0) of metallic models and electric field supplied.

right side of Fig. 4, the surface area of the lead disk was decreased by only one perforation. Similar crystals of this doughnut type do not exist in nature, however, it corresponds to a crystal of stellar type or combination of bullets in which openings are large. The diameter of the perforation and the percentage of the area are shown in the lower part of the right figure. The horizontal axis shows the electric field ($KV \cdot m^{-1}$) and the vertical axis shows the ratio ($Q \cdot Q_0^{-1}$) of the final charges of the perforated disk (Q) to non-perforated disk (Q_0). Compared with the same percentage of perforated area, for instance, the percentage of area of the lead disk, 81.6%, 9 perforations of 1 mm diameter in (A) and 1 perforation of 3 mm diameter in (B), it is understood that the small perforations have no effect on its final charges as shown in the left figure. On the other hand, the large perforations are more effective than the small ones, and the effect tends to decrease as the electric field supply increases.

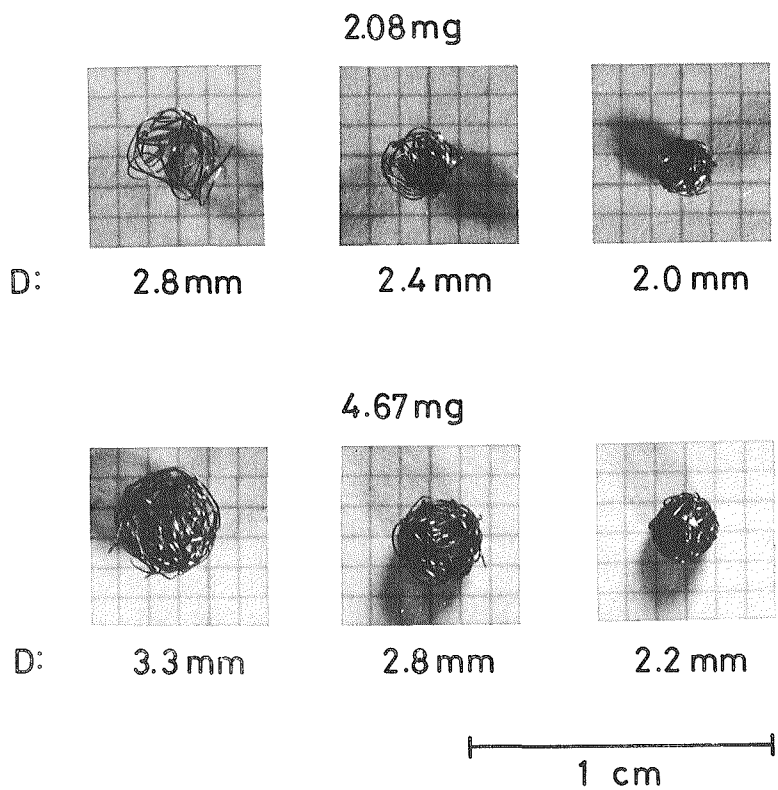

Fig. 5 Photographs of metallic models simulating snowflakes.

From these results, it may be understood that the final charge of the fine structured plane snow crystals such as a "dendrite" would be possible to approximate the charge of the disk of the same external diameter.

Next, the final charges of the metallic models simulating snowflakes were examined. The metallic models were made of a steel wool 0.025 mm in strand diameter and rolled into a ball. The measurements were carried out by several different external diameters of steel wool strands. For different weights of steel wool strands of 2.08, 4.67, 6.18 and 7.14 mg were examined. Fig. 5 shows the rolled steel wool strands examined. The results of measurements are shown in Fig. 6. In the figure, the same shaped symbols mean the same steel wool strand. The lines show the theoretical final charges of spherical conductor under the electric fields supplied. The final charges of metallic snowflake model are also the same quantity of the same external diameter spherical conductor.

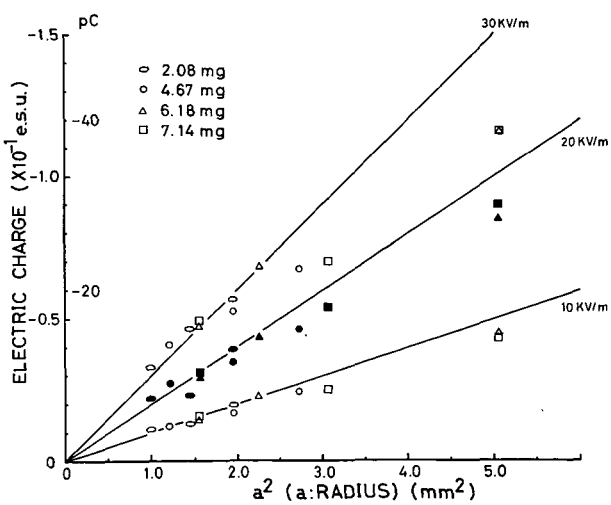

Fig. 6 Relation between electric charge and square of radius of metallic models of Fig. 5 under various electric fields.

From the experiments with metallic models simulating plane snow crystals and snowflakes, the final charges of them by the ion-capture process depend on their external diameters and the electric fields supplied and do not depend on their fine structure and their porosity.

3.3 Results of ice particles (ice spheres, graupel particles, and snowflakes)

In this experiment, the same apparatus was transferred into the cold room and the experiment was carried out with ice spheres or natural ice particles. The spheres examined were produced by freezing of water drops. The results are shown in Fig. 7. The straight lines show the theoretical final charges in the case where it was assumed that the ice sphere is spherical conductor. Therefore, the ice sphere can be regarded as spherical conductor the same as in Abbas and Latham's experiment.

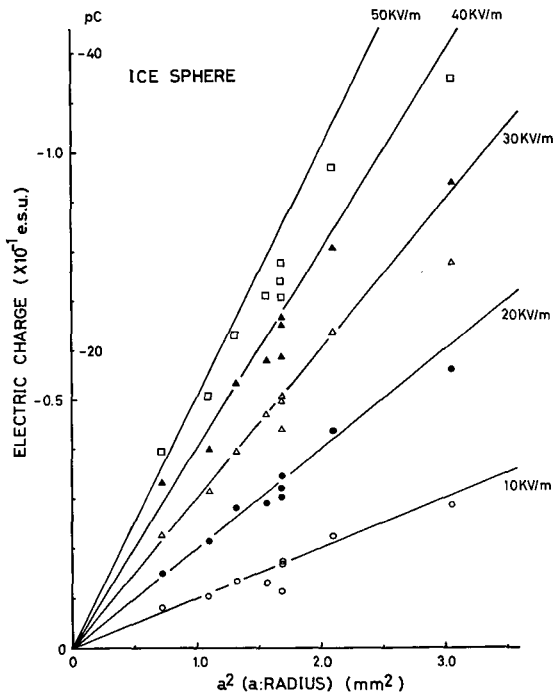

Fig. 7 Relation between electric charge and square of radius of artificial ice spheres under various electric fields.

The final charge of natural graupel particles collected on Dec. 20, 1981, at Sapporo, were similarly measured. One of the samples examined is shown in Fig. 8. As their base is orientated downwards, the graupel particles were suspended with their base oriented to the ionic stream source in order to catch ions in this experiment. The electric field supplied in this experiment was

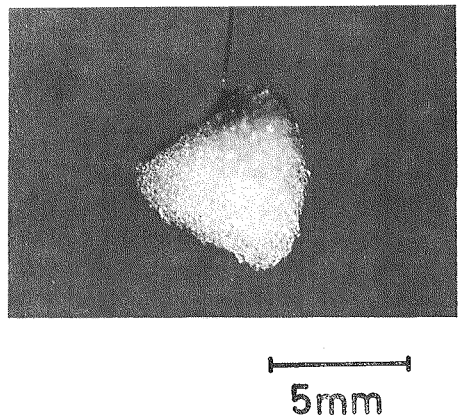

Fig. 8 A photograph of graupel particle examined.

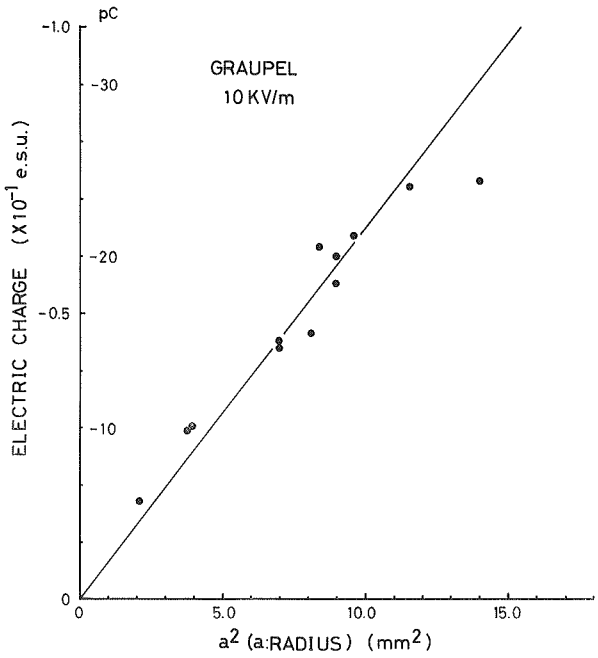

Fig. 9 Relation between electric charge and square of radius of graupel particles under an electric field of $10\mathrm{KV \cdot m^{-1}}$.

$10\mathrm{KV}\cdot\mathrm{m}^{-1}$. The radius of graupel particles was defined as the radius of their base. The results are shown in Fig. 9. The experimental formula of the relation between the final charges and their radius is

$$Q = -0.65a^2 \qquad \text{(esu)}\,.$$

The final charge is proportional to the electric field supplied. Thus, it becomes

$$Q = -1.95Ea^2 \qquad \text{(esu)}\,.$$

Since the shape of graupel particles is a circular cone, the final charges are about 2/3 times of the final charge of the spheres.

The final charge of snowflakes made artificially by gathering natural snow crystals was measured, likewise. One of the samples examined is shown in Fig. 10. The results are shown in Fig. 11. The straight line shows the theoretical final charge of the spherical conductor. Therefore, snowflakes electrically behave as spherical conductor the same as in the results by a metallic model described previously. From the experiments as a whole, interesting results were obtained. Namely, the final charges of precipitating particles such as dendritic shape of snow crystals or snowflakes closely resembled their external shapes and their external diameters. Hence, the final charges of dendritic shape of snow crystals are approximately the same as those of the disk and those of snowflakes are to those of spheric conductors.

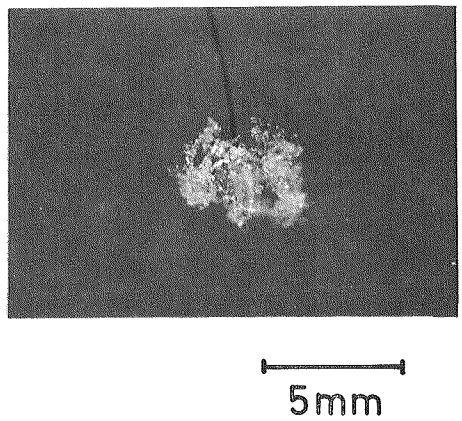

Fig. 10 A photograph of snowflake made artificially by gathering natural snow crystals.

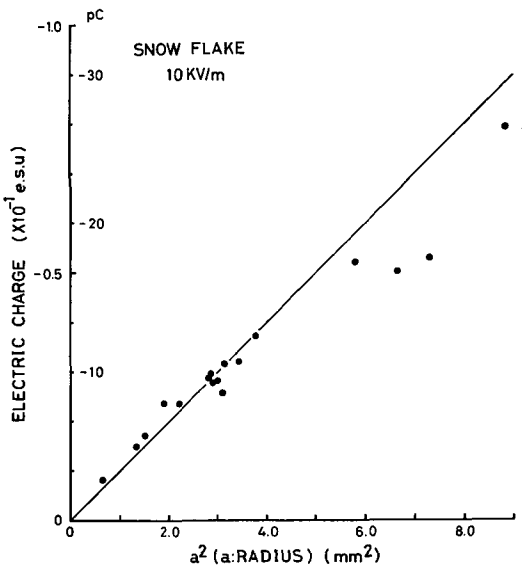

Fig. 11 Relation between electric charge and square of radius of snowflakes under an electric field of $10\mathrm{KV}\cdot\mathrm{m}^{-1}$.

4. Concluding remarks

In order to clarify "the inverse relation" and "the mirror image relation" between the atmospheric electric field strength (potential gradient) and the electric charges on precipitation particles, experiments of the charging mechanism of precipitation particles by "the ion-capture process" were carried out using water drops, metallic models for ice particles, artificial ice spheres, graupel particles, and snowflakes. As a result, although the dendritic shapes of snow crystals and snowflakes have a number of small openings, their final charges obtained by the ion-capture depended on their external shapes and their external diameters. Namely, it was regarded as appropriate to simulate the dendritic shape of snow crystals to conducting disks and snowflakes to spherical conductors. Therefore, it was understood that the final charges of natural snow crystals are greater than those of rain drops which have the same mass of snow crystals. Further, it was expected that the high porosity of snow crystals, for instance, the dendritic shape of snow crystals and snowflakes of dendrites, leads to increase the collection efficiency of ions. As a result, snow crystals require a shorter time to reach the final charges than rain drops having no porous surface.

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